Japanese “Namazu”
1356, Basel, Switzerland
1755, Lisbon EQ
Early Chinese Seismoscope
Modern seismometer
1971, San Fernando Valley
San Andreas Fault
San Andreas fault
San Andreas fault (infrared)
San Andreas fault, north of San Francisco
Fault scarp near Crowley Lake, CA
1906, San Francisco

Also, Tokyo, 1927
1906, San Francisco
1906, San Francisco
1906, San Francisco
1906, San Francisco
1989, Loma Prieta EQ: Bay Bridge
1989, Loma Prieta EQ: Nimitz Freeway
1995, Kobe Earthquake
1995, Kobe Earthquake
1989, Loma Prieta EQ: Marina District, San Francisco
Recordings of a magnitude 5.0 aftershock of the Loma Prieta earthquake illustrate intense local amplification of ground shaking in the Marina district of San Francisco.
1971, San Fernando (Los Angeles)
1994, Northridge
(Los Angeles)
1971, San Fernando Valley (Los Angeles)
1971, San Fernando Valley (Los Angeles)
1964, Niigata, Japan
1989, Loma Prieta, CA
Novaya Zemelya Nuclear Test Site
Data recorded at Nilore, Pakistan

05/11/98 Indian Nuclear Test
(Magnitude 5.1)

04/04/95 Indian Earthquake
(Magnitude 4.8)

Surface Wave

Time (s)
Three-component Records at MDJ (Mudanjiang, NE China) from the Presumed North Korean Nuclear Test on 9 October 2006 (ML 3.9, Shallow) and a near by Earthquake on 16 December 2004 (Mw 4.0; h= 8 km)

Unt Z
9.7 micrometer/s
ML 3.9
2006/10/09

Unt NS
9.5 micrometer/s
ML 3.9
2006/10/09

Unt EW
8.1 micrometer/s
peak amplitude
2006/10/09

Earthquake Z
11 micrometer/s
Mw 4.0
2004/12/16

Earthquake NS
12 micrometer/s
Mw 4.0, h=8 km
2004/12/16

Earthquake EW
19 micrometer/s
peak amplitude
2004/12/16

Rayleigh wave

371.1 km
az=6°
baz=186°

341.6 km
az= 23°
baz=204°

Lamont-Doherty Earth Observatory of Columbia University
Russian earthquake/explosion
Figure 1.2-18: Yields of Soviet underground nuclear tests.
Figure 1.2-4: Isoseismals of the Dec. 16, 1811, New Madrid earthquake.
Ground-shaking hazard from earthquakes

eqhazmaps.usgs.gov
EQ Prediction: Groundwater chemistry and pressure
Figure 1.2-17: Radon emissions before and after the 1995 Kobe earthquake.

Earthquake Prediction: Groundwater chemistry
Earthquake Prediction: Animal Behavior

Figure 10.7 Cartoon in Chinese seismological textbook, suggesting that animals may give forewarnings of earthquakes. “Chickens fly up to trees and hogs stay quiet. Ducks go out of water and dogs bark wildly.” [Courtesy of W. Lee and Francis Wu.]
Figure 1.2-16: Loma Prieta seismic gap along the San Andreas.
Location of August 17, 1999 Turkish Earthquake

- Historical earthquake epicenter and magnitude
- Extent of surface rupture
- Directions of relative motion on fault
EQ Forecasting

But, must also remember the “New York City bear gap hypothesis
Figure 1.2-15: Paleoseismic time series for the San Andreas near Pallett Creek.
But, cannot tell if it is probabilistic (e.g., Gaussian) or random
Didn’t occur until 2004 (16 years late!)
Parkfield, CA
A CASE STUDY: THE DECEMBER 26, 2004, SUMATRA EARTHQUAKE
The process of subduction that has created Indonesia through volcanic activity, also makes it dangerous.
INDIAN PLATE MOVES NORTH COLLIDING WITH EURASIA
COMPLEX PLATE BOUNDARY ZONE IN SOUTHEAST ASIA

Northward motion of India deforms all of the region

Many small plates (microplates) and blocks
The Indian plate subducts beneath the Burma microplate at about 5 cm/yr. Earthquakes occur at the plate interface along the Sumatra arc (Sunda trench). These are spectacular & destructive results of many years of accumulated motion.
STAGE 1: INTERSEISMIC:

India subducts beneath Burma microplate at about 5 cm/yr

Fault interface is *locked*
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India subducts beneath Burma microplate at about 5 cm/yr

Fault interface is *locked*

STAGE 2: EARTHQUAKE (COSEISMIC):

Fault interface *slips*, overriding plate rebounds, releasing accumulated motion
STAGE 1: INTERSEISMIC:

India subducts beneath Burma microplate at about 5 cm/yr

Fault interface is *locked*

STAGE 2: EARTHQUAKE (COSEISMIC):

Fault interface *slips*, overriding plate rebounds, releasing accumulated motion

Fault is locked

Fault ruptures

Fault slipped ~ 10 m = 1000 cm  
$\frac{1000 \text{ cm}}{5 \text{ cm/yr}} \approx 200 \text{ yr}$

Faults aren’t exactly periodic for reasons we don’t understand.
MODELING THESE SEISMOGRAMS shows how slip varied along the fault plane.

Most slip along an area ~400 km long

Maximum slip ~ 20 m
For comparison, a magnitude 5 earthquake would rupture a patch roughly the size of New York City's Central Park.
Land drops during earthquake → Buried soil of killed marsh and forest

Before: Happy tree, Soil, Mud
Minutes: Sad tree, Tidal water
Months: Dead tree
Centuries after: New plants growing on top

[Courtesy of B. Atwater]
1700 forest

Modern salt marsh

[Courtesy of B. Atwater]
Computed tsunami wave from a M 9 Cascadia earthquake

Time = 4 hours after the earthquake

[after Satake et al., 1996]

[Satake et al., 1996]
Japanese Tsunami Records

[Satake et al., 1996]
History of large Juan de Fuca Earthquakes based on submarine landslide deposits

- 2780
- 2170
- 1190
- 690
- 300

Years before present

980 year interval
390 years

(data from Adams, 1990)
TSUNAMI - water wave generated by earthquake

1. Earthquakes cause the ocean floor to collapse in places and rise elsewhere, displacing water and generating waves.
2. Initial waves, largely underwater, travel very fast toward the shore.
3. In the shallow waters near the shore, the waves decrease in speed while rising in height above the surface.
4. The tsunami reaches the shore, causing severe flooding and extreme currents.

SOURCES: Staff reports, Associated Press
ILLUSTRATION BY THE ASSOCIATED PRESS; GRAPHIC BY THE WASHINGTON POST
Banda Aceh:
Before....
Banda Aceh:
Before....

and

After.....
IN DEEP OCEAN tsunami has long wavelength, travels fast, small amplitude - doesn’t affect ships

AS IT APPROACHES SHORE, it slows. Since energy is conserved, amplitude builds up - very
TSUNAMI SPEED IN DEEP WATER of depth $d$

$$c = (gd)^{1/2}$$

$g = 9.8 \text{ m/s}^2$

If $d = 4000 \text{ m}$, then

$$c = 200 \text{ m/s} = 720 \text{ km/hr}$$
$$= 450 \text{ km/hr}$$

Tsunami generated along fault, where sea floor displaced, and spreads outward

Courtesy of K. Sataki
Tsunami waves bend around “obstacles” like islands and peninsulas in a process called DIFFRACTION.

Image Source: K. Sataki
http://staff.aist.go.jp/kenji.sataki/Sumatra-E.html
The Tsunami Eventually Crossed All Oceans
Rays Bend as the Water Depth Changes

The Density of Rays Shows the Focusing and Defocusing due to REFRACTION

Ray paths for tsunami generated by the 1960 Chile earthquake.

1 hour
Seen safely from high ground, a wave of the 1960 Chilean tsunami pours into Onagawa, Japan.
Wave that devastated part of Hilo

First wave of tsunami

Approximate low tide level

TSUNAMI OF MAY 23, 1960, ON THE ISLAND OF HAWAII
1946, Hilo Harbor (from Alaskan EQ)
Pacific Ocean Tsunami Warning System
1755, Lisbon EQ
Giant Eruption of Krakatau in 1883.

From Simkin and Fiske, 1983
The tsunami from the 1650 BCE eruption of Mt. Thera may have destroyed the Minoan culture on Crete, and given rise to the legend of Atlantis.
So….Could this Happen in America?!?
Massive landslides in places like the Canary Islands could cause enormous Atlantic tsunamis!
There have also been Giant Undersea Landslides in the Puerto Rico Trench
An enormous tsunami from the Chixulub impact washed over North America 65 million years ago.
“CIVILIZATION EXISTS BY GEOLOGICAL CONSENT, SUBJECT TO CHANGE WITHOUT NOTICE”
(Will Durant)

The same geologic processes that make our planet habitable also make it dangerous